KEK-PREPRINT-92-70
Fermilab Library
0 1160 0011322 9

KEK Preprint 92-70
July 1992
A

Recent Progress in R&D Work for the Japan Linear Collider

Koji TAKATA

Contributed to the XVth International Conference on High Energy Accelerators, Congress Centrum, Hamburg, Germany, July 20-24, 1992.

FERMILAB
SEP 1992

National Laboratory for High Energy Physics, 1992

KEK Reports are available from:

Technical Information & Library
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305
JAPAN

Phone:	0298-64-1171	
Telex:	3652-534	(Domestic)
	(0)3652-534	(International)
Fax:	0298-64-4604	
Cable:	KEKOHO	

RECENT PROGRESS IN R&D WORK FOR THE JAPAN LINEAR COLLIDER

KOJI TAKATA
KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

Recent results of R&D works for the Japan Linear Collider (JLC) are summarized for the following topics: (1) novel electron sources, (2) high power X-band klystrons, (3) X-band structure studies including high gradient tests, (4) the final focus system and (5) design studies for a 1.54GeV test damping ring to be constructed at the accelerator test facility(ATF).

1 Introduction

We started R&D works at KEK in 1987, aiming at construction of JLC, a TeV linear collider in Japan. The JLC will cover the center-of-mass energy range from 300GeV to 1 TeV with luminosities more than several times $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Our design philosophy has been to employ well-established linac technologies for the main linac, except for the RF frequency raised to 11.4GHz, four times the well-known S-band one. The average acceleration gradients of the main linac ranges from 50 MeV/m to 100MeV/m, which are fairly higher than those of conventional linacs. The activity comprises such subjects as: (1) parameter optimization including theoretical analyses of beam-beam phenomena at the interaction point, (2) construction of an S-band linac and 1.54GeV test damping ring at ATF, (3) separately going R&D works for electron/positron sources, X-band klystrons, X-band structures, and the final focus system. In this report highlights are described of their recent results.

2 JLC parameters

The JLC will start with the center of mass energy around 500GeV and reach 1 TeV along with progresses in RF technologies. Main design parameters for 500GeV are shown in Table 1, where two extreme cases for the bunch number per pulse are considered with the total number of particles kept constant at 8×10^{11} per pulse. Similar calculations suggest a luminosity of $8.8 \times 10^{33}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ for the energy 1 TeV with the doubled accelerating gradient and other small changes in beam parameters. A major problem in this parameter optimization is the total AC power necessary. It would be around 100MW for the 500GeV 20-bunch option but be as high as 300MW for 1TeV. We think it should practically be less than 200MW. Therefore we might have to halve the repetition rate and hence the luminosity for the 1TeV case. Finally we add that a lower RF frequency, for instance 5.7GHz, half the X-band frequency, provides better parameter sets with higher luminosities, if we restrict ourselves only to energies 500GeV or less. But R&D works for the main linac shall be carried out only for the X-band case, unless a low energy option becomes urgently required in near future.

Table 1: Main JLC parameters for $E_{CM} = 500$GeV

Inter-bunch distance/nsec	1.4	
Repetition rate/pps	150	
Total length/km	25	
Damping ring energy/GeV	1.98	
RF frequency/GHz	11.424	
Acc. struct. length/m	1.22	
Average gradient/MV/m	40	
Nr. of struct. per beam	7800	
Input RF per struct./MW	50	
Nr. of bunches per pulse	20	90
Nr. of particles per bunch	1.2×10^{10}	0.7×10^{10}
RF pulse length/nsec	100	200
Ver. emitt. dilut. in linac/%	50	50
Crossing angle/mrad	6	7.2
Inv. hor. emitt. ε_x^*/rad-m	5.5×10^{-6}	3.3×10^{-6}
Inv. ver. emitt. ε_y^*/rad-m	7.5×10^{-8}	4.5×10^{-8}
Bunch width σ_x^*/nm	335	260
Bunch height σ_y^*/nm	4.5	3.0
Bunch length σ_z^*/μm	113	70
Luminosity/$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$	2.4×10^{33}	6.3×10^{33}

3 Novel electron sources

3.1 RF gun

First electron beams of relativistic energies($\sim$ 900keV) were obtained with a single cell S-band cavity and a

photocathode irradiated by 20ps laser pulses at an interval of 5.6ns[1]. The number of electrons per bunch was around 2×10^{10}. For the cathode, a Cs_3Sb surface 16 mm in diameter was used, which was, after cesiation, irradiated by 532nm 110μJ laser pulses. The cathode had a quantum efficiency of about 7×10^{-5} and a life of a few hours. One of the major problems was jitters on the order of several tens of picoseconds of laser pulses with respect to S-band RF, which has prevented us from measuring beam emittances accurately.

3.2 Polarized electron source

To get the 100% polarization, we have developed two kinds of photocathodes. One is a GaAs-AlGaAs superlattice, the other a lattice-mismatched strained GaAs surface, with which we obtained polarizations of 71% and 86%, respectively[2][3]. Employing these techniques, we are developing a prototype 200kV gun which will be used as an injector at the ATF.

4 X-band klystron

We began R&D of high power klystrons in two steps. At first medium power tubes of XB-50 type were developed. They were designed to provide an output power of 30MW at 450kV with a 0.6μ perveance beam generated by a cathode 50mm in diameter. Secondly we are developing larger tubes of XB-72 type having a cathode 72mm in diameter with 1.2μ perveance[4].

For the XB-50 type, we first fabricated a diode tube and tested it successfully up to the beam voltage 480kV with 2μs pulses. Its perveance was verified to be the same as designed. The first XB-50 type klystron has ever produced a peak output power of 18MW for the 100ns pulse length and 2pps repetition at a beam voltage of 403kV. The RF efficiency was 32%, whereas 42% had been predicted by the 2.5 dimensional simulation code FCI[5]. The tube has been used with 100pps 50ns long pulses for 600 hours for an X-band high gradient test as described below .

The first XB-72 klystron was tested in April 1992. We obtained a peak output of 24 MW for the 100ns pulse length at the beam voltage 430kV. It suffered from vacuum leaks due to pin holes at the gun bushing and is under repair. The RF conversion efficiency was only 15% at this voltage, while FCI simulations predicted 33%. This discrepancy might be partly due to a difference between the actual field pattern at the output cavity gap and a one assumed in the simulation.

5 X-band structure

5.1 high gradient test

The test has been carried out for a conventional $2\pi/3$ CZ 20cm long structure having 22 cells with an aperture diameter 2a of 6.0 mm[6]. Its shunt impedance is 104MΩ/m with the total attenuation parameter τ being equal to 0.284. The peak surface field is 1.96 times the average gradient. The calculated average gradient is 87MV/m for the 30MW input power. Using the above XB-50 klystron to generate 50 ns long RF pulses at repetition rates of 10 to 100pps, we conditioned the structure to an averaged gradient of 70MV/m in 500 hours. Peak dark currents downstream the structure were about 600μA at the highest gradient, where the enhancement factor β was about 35.

To treat dark current phenomena more generally, a simulation code ETS(Electron Trajectory Simulation) was developed[7]. We simulated spectra of transmitted currents and also limiting values for the RF voltage and phase within which electrons can be transmitted through a structure. The minimum gradient for transmission is calculated to be about 30MV/m for an 2.86GHz structure, 80 for 11.4GHz and 180 for 30GHz. For each frequency, the phase area for transmision ranges roughly $\pm 30°$ around the crest and almost independent of gradients. Energy spectra simulated for a 67 cm long S-band TW structure were compared with experimental data. The both seem to agree each other except for the absolute value of currents for gradients between 60 and 80MV/m.

5.2 high precision machining

We are carrying on high precision machining studies at KEK for OFHC-copper regular cells and coupler cells. Dimensional accuracies are required to be on the order of 1μm or better. About 40 unit cells were fabricated with a lathe which were carefully tuned up for this purpose. Dimensions of machined pieces were measured with such devices as a precision 3D measuring apparatus, electron microscope and laser interferometer. The results seem hopeful.

5.3 detuned structure

Using an equivalent circuit model for a 150 cell structures(1.3m long) with an average beam aperture radius of 0.16λ, we have carried out estimations for long range wakes of the TM_{11} mode. We assumed that each cell is so detuned that the TM_{11} mode has a gaussian distribution with $\sigma = 0.375$ GHz centered at 15.6GHz. For this detuned structure the transverse wake potential per unit

length is calculated to be less than $1 \times 10^{15} VC^{-1}m^{-2}$ during 25ns after a bunch left the structure. The emittance growth due to this wake would be within a tolerable limit of 1×10^{-9} rad-m for a 20 bunch train, if we assume structure alignment errors to be on the order of $10\mu m$.

5.4 damped structure

Simulation studies have been focused on a structure which has 4 waveguides per cell to damp higher order modes. For TM_{11} modes in particular, external Q values as small as 20 are required. Structure dimensions have been found to achieve the above condition while keeping a loss of the Q value of the accelerating mode within an acceptable range. Instead of conventional waveguides, the possibility of using a radial transmission line is also considered[8]. If a suitable choke section is attached, this scheme provides a strong damping for almost all modes and yet has only a little influence over the accelerating mode.

6 Final focus

6.1 optics design

The optics design has been concentrated on getting the largest possible momentum bandwidth by use of two family sextupole chromaticity correction scheme[9]. The total length per beam will not be larger than 500m with the bend angle around 5mrad. By making unequal horizontal dispersions at the correctors, a bandwidth as large as $\pm 0.8\%$ was obtained. Detailed estimations have been made for displacement errors, field strength errors and rotational errors of every magnets on the line. For instance the final quad requires the severest tolerance 0.2nm for the displacement, while the others on the order of 100 nm. An important issue is resistive wake fields on the poles of the final quad. To avoid the beam breakup due to this effect, the aperture of the quad is made as large as 6.6mm in diameter. Another one is the background problem at the interaction region[10]. Careful estimations of the background led us to choose a rather long distance of 2m between the interaction point and the face of the quad.

6.2 hardwares

R& D studies for hardwares for the final focus have been in close connection with the FFTB project at SLAC. First, we are fabricating three final quads for the FFTB: the last one QC1, penultimate one QX1 and pre-penultimate one QC2. Each length is 1.1m, 30cm and 2.0m, respectively. QC1 and QC2 have iron yokes, while QX1 has Fe-Co yokes. QC1 has an aperture radius of 6.5mm, and its pole surfaces were machined and assembled with accuracies about $\pm 2\mu m$. A 1m wide and 4.5m long table was also manufactured to place the three quads[11]. A combination of stepping motors and piezo-electric actuators corrects positions with accuracies of $50\mu m$ and $0.5\mu rad$, when the table is loaded with the total quad weight of 8 tons. Secondly, a novel beam profile monitor based on the compton scattering effect is being developed, which will be also tested at the FFTB[12]. An electron bunch, passing through a standing wave field of a laser light, will generate compton-scattered γ rays whose intensity is proportional to the light electric field squared. Using the second harmonics of a YAG laser, we expect a profile resolution as small as 40nm.

7 Test damping ring construction at ATF

Since 1987, we have been constructing an S-band linac at the ATF. The main purpose of the ATF is to construct a 1.54GeV test damping ring with the linac serving as its injector. Reconstruction of a building to install the accelerators is in progress. The ring will have a circumferential length of139m. It consists of arcs with combined function FODO cells and 24m long wiggler sections. The main goal is to achieve the normalized emittances less than 5×10^{-6}rad-m horizontally and 5×10^{-8}rad-m vertically, for a 20 bunches with a separation of 1.4ns and population of 2×10^{10} particles per bunch[13].

References

[1] M. Yoshioka *et al*, contribution to this conference

[2] T. Nakanishi *et al*, Physics Letters A158 (1991) 345

[3] T. Omori *et al*, Phy. Rev. Letters 67 (1991) 3294

[4] H. Mizuno, contribution to this conference

[5] T. Shintake, KEK Report 90-3, 1990

[6] T. Higo *et al*, Proc. of the 16th Linear Acc. Meeting in Japan, Sep. 1992

[7] S. Yamaguchi, submitted to Nucl. Instr. & Meth.

[8] T. Shintake, KEK Preprint 92-51, 1992

[9] K. Oide, contribution to this conference

[10] T. Tauchi, submitted to Particle Accelerators

[11] N. Ishihara *et al*, contribution to this conference

[12] T. Shintake, Nucl. Instr. & Meth. A311 (1992) 453

[13] J. Urakawa *et al*, contribution to this conference